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Producing High Energy ns Pump Beams for Raman Amplification of Short Pulses using SBS Beam Combination

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Livermore , CA, United States
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Presentation at IZEST

Livermore Ca. July 18, 2013

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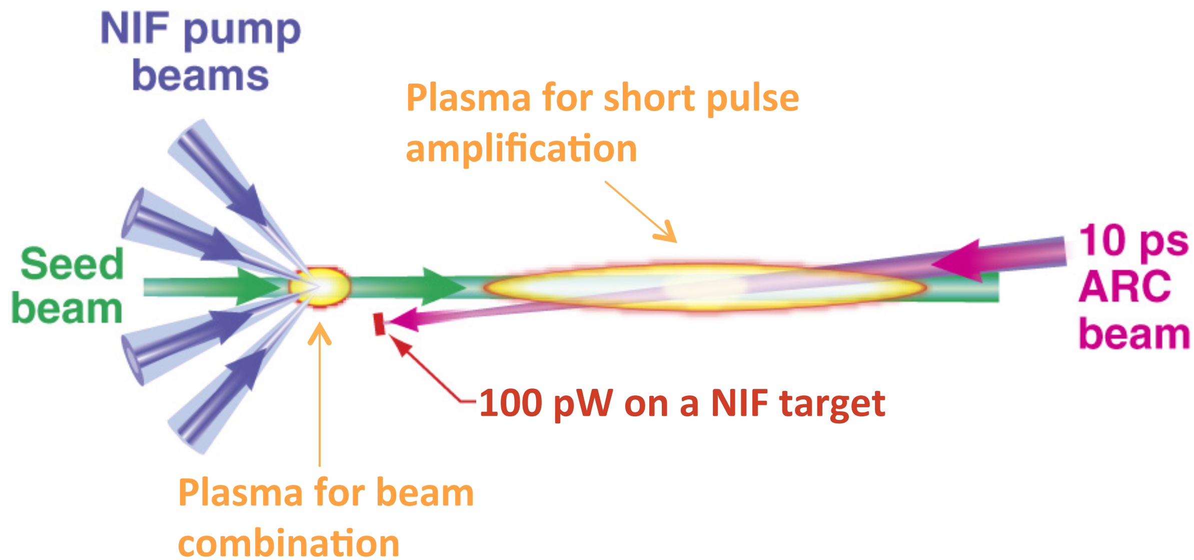
Plasma Amplification can allow pulse compressors to access the energy in many beams at NIF or other lasers

Concept for producing high energy short pulse at NIF



Depletion of a 1 ns pump beam by a ps seed will require 15 cm of plasma for interaction

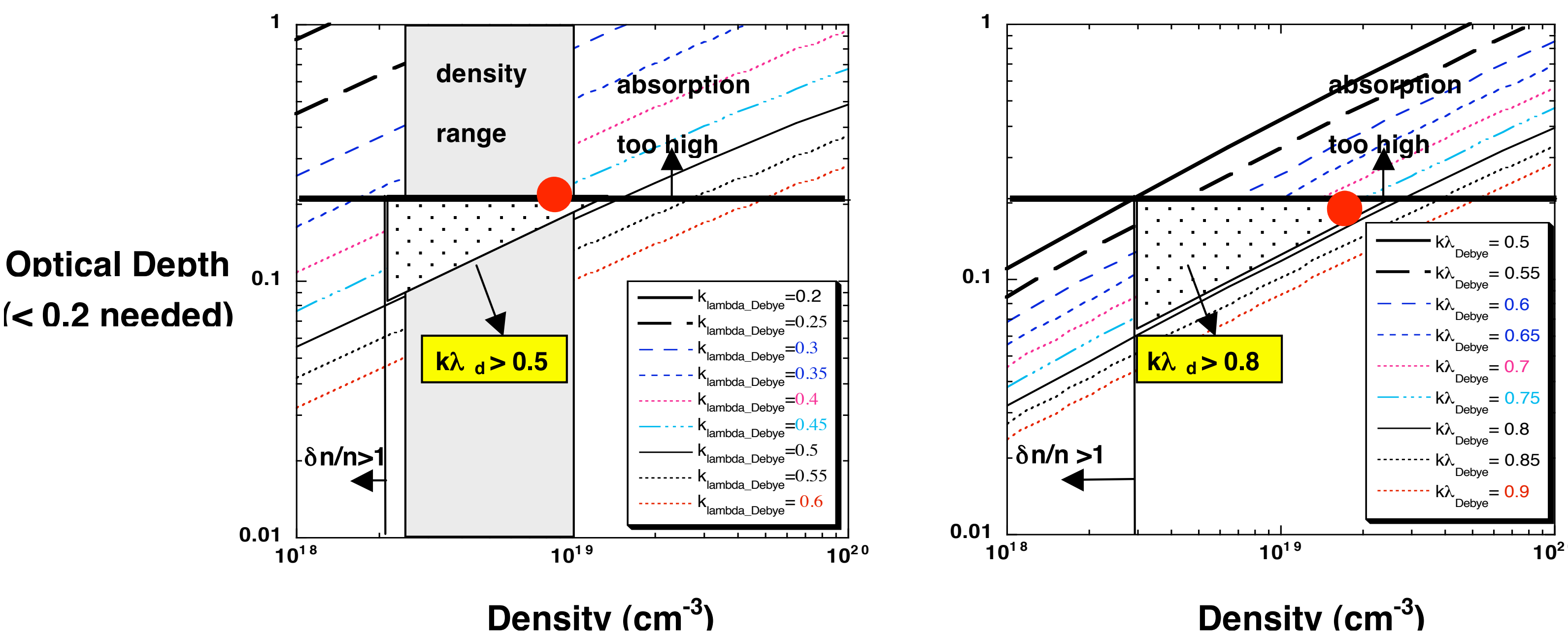
-> to avoid absorption the plasma must be hot and low density (high kL_D)
-> strong linear damping of Langmuir waves at high kL_D requires high intensity

An attractive concept is a single collimated high intensity pump/heater of ns duration that Is well collimated and intense through out the interaction region. This will naturally Create a uniform density plasma in a gas that is heated to high temperature.

Such a pump can be produced via ion wave amplification/combination in a second plasma

Low absorption, and moderate density leads to strong damping in the Raman amplifier *requiring high pump intensity*

1054 nm pump wavelength | **351 nm pump wavelength**



Limiting absorption and avoiding wave breaking push the Raman amplifier to high kL_D plasmas where significant pump intensity is need to drive waves.

The conditions identified for 1 micron beams were studied at Jupiter in ‘09 where

1) 77x amplification of a weak seed was demonstrated [1,2].

2) Wave saturation effects were found to be describe by 2D VPIC [2,3].

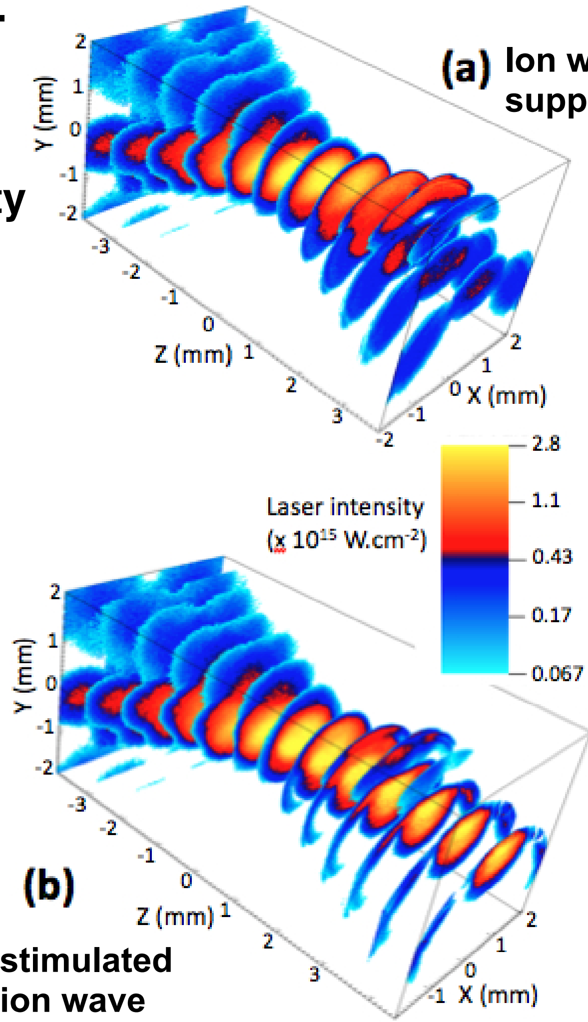
Further development of the Raman amplifier section is TBD [4].

[1] Ping PoP (2009), [2] Kirkwood JPP (2010), [3] Yin PRL (2012) [4] Trines PRL 2012

The physics needed to combine ns pump beams by SBS has been demonstrated by the ignition program

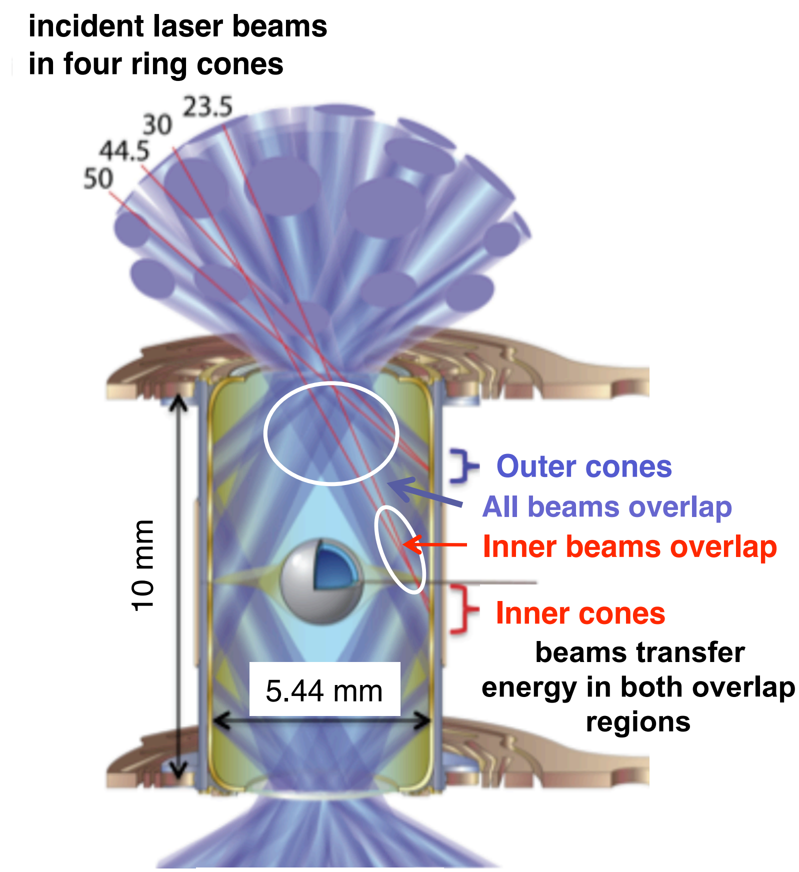
The beam propagation in the beam crossing region of the ignition target demonstrates beam amplification.

Note:
One beams intensity is increased 6x and overall energy is increased 2x with energy from the other beams when the beams wavelength are tuned near resonance.



(a) Ion waves suppressed

(b) stimulated ion wave scatter included



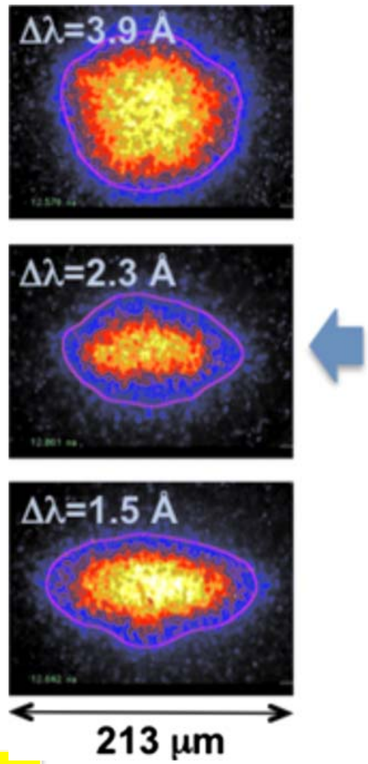
D. E. Hinkel LLNL

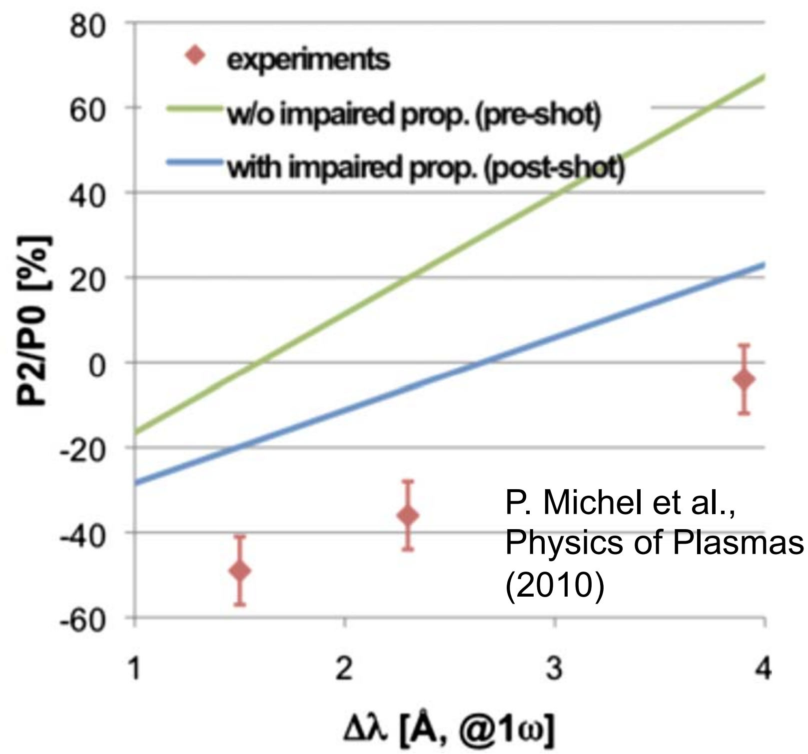
J. D. Moody et al., Nature Physics (2012)

Ion wave amplification is already used to control the symmetry of the ignition target implosion

X-ray images of a converged capsule show the effect of the amplification of the beams at the waist, which squeeze it into a ‘pancake’ when their wavelength is tuned.

The observed capsule Symmetry is seen to track The expected value when ion wave amplification is accounted for.



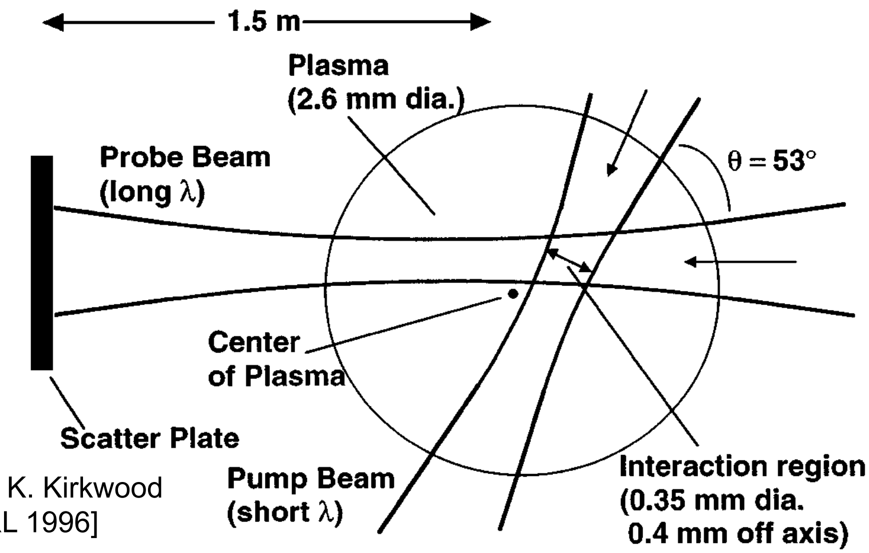


This ‘wavelength tuning’ is now the primary means of controlling drive symmetry in the ignition targets and has been necessary for demonstrating good implosion symmetry.

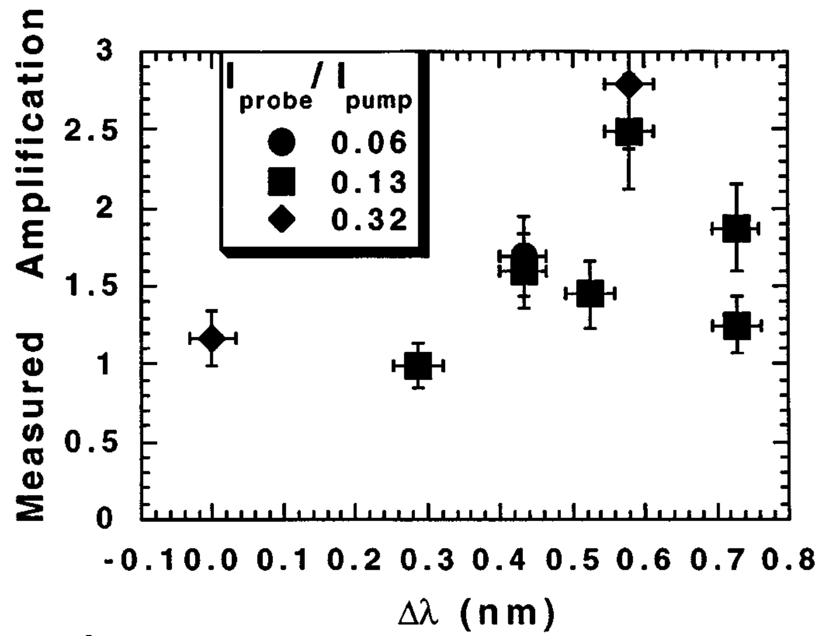
To bring the measured symmetry into agreement with models a saturation of the ion wave amplitude ~ $dn/n = 4.4\text{e}{-4}$ has been invoked, and new models developed.

Saturation can have an effect on power transfer!

Nova: amplification of a single beam in a gas target plasma is controlled by its wavelength



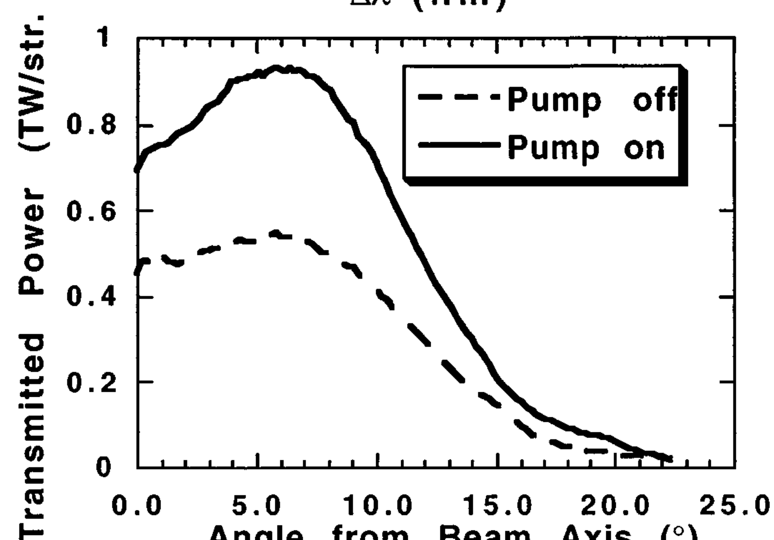
[R. K. Kirkwood PRL 1996]



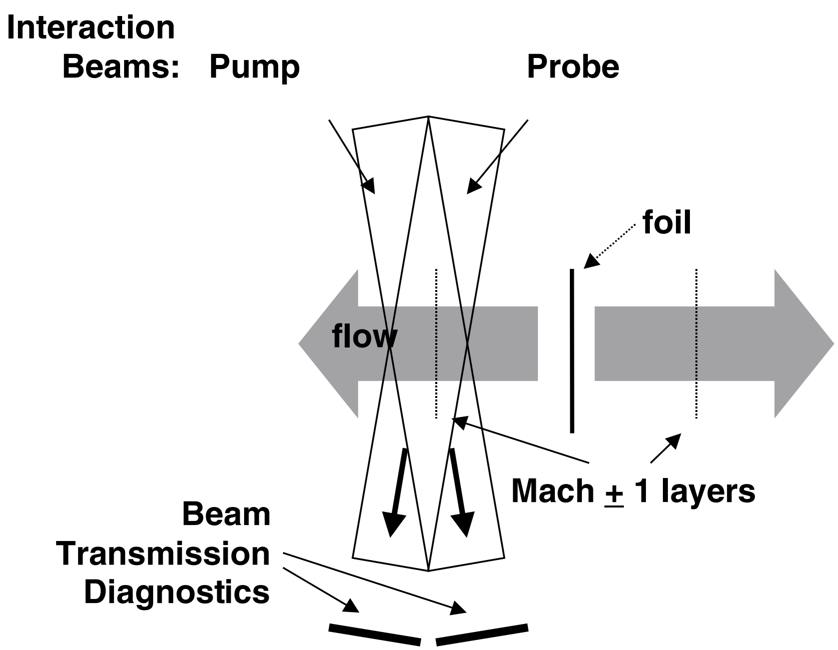
A gas-filled bag created a uniform 2.6 mm diameter plasma with conditions allowing a 2.8 x amplification of a seed beam that transferred 1 kJ (40%) of the pump beams energy at Nova.

The amplification was controlled by the seed Wavelength.

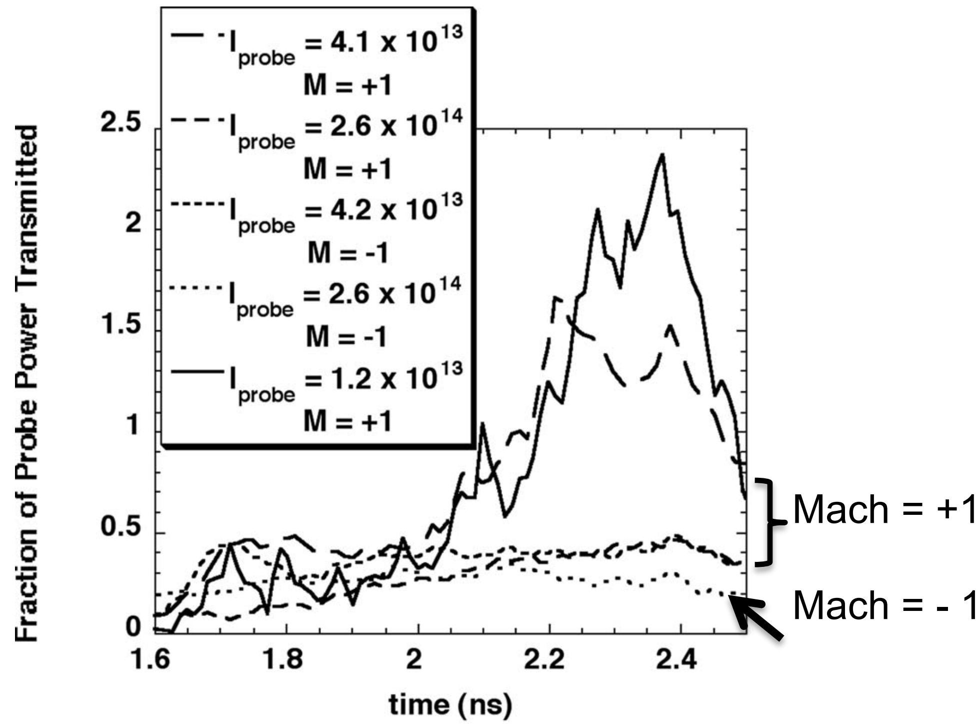
The amplified beam had the same (or better) collimation than the incident beam.



Omega experiments in 2002-5 showed saturation that motivated present NIF models



[R. Kirkwood et al. PRL 2002 and PoP 2005]

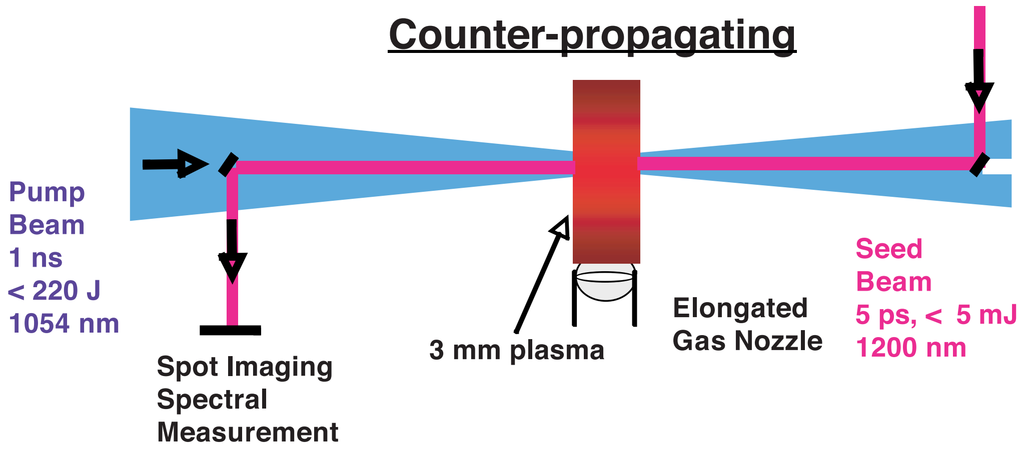


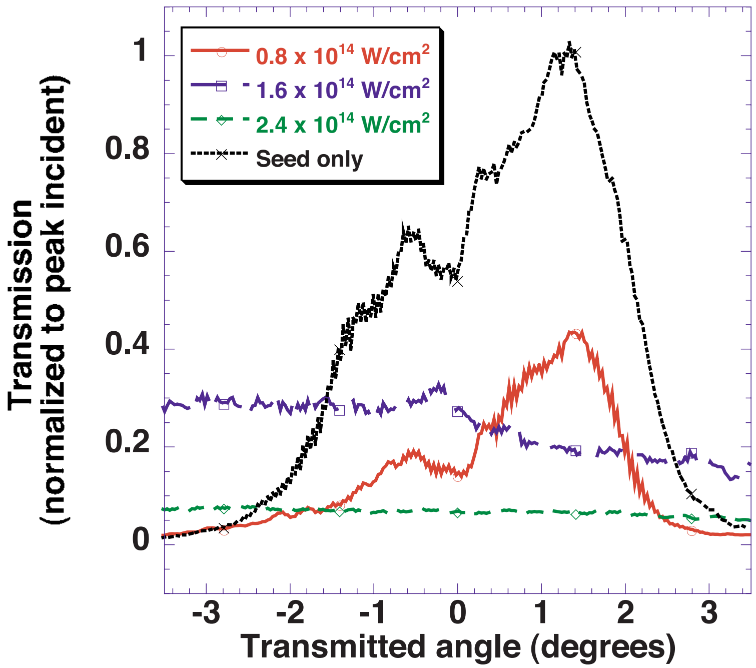
Omega experiments use same frequency pump and seed beams with Mach = +1 flow in plasma to match resonance on one side of a CH or Al exploding foil.

Observed amplification was as much as 4x when the probe beam intensity was weak.

Amplification was observed to reduce with probe intensity, ***also indicating saturation***.

Jupiter Experiments have also shown good focal quality is maintained in the absence of pump filamentation





Plasma density = 1% critical
Plasma length = 1 mm
Laser wavelength = 1 μm

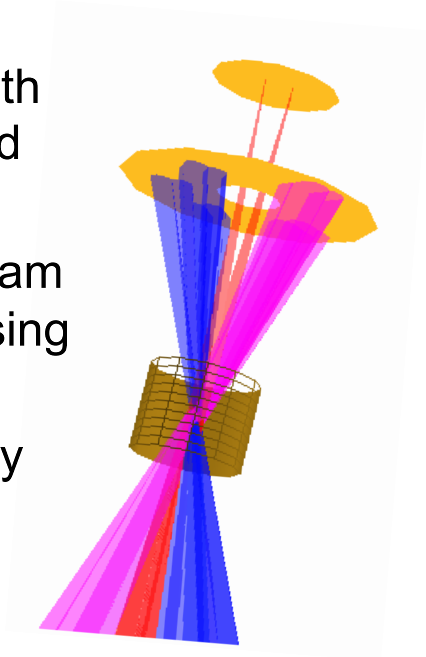
[Y. Ping et al. PoP 2009]

Experiments at Jupiter have also shown that when the average intensity of a phase plate smoothed pump beam is below 4% of the filamentation threshold intensity, the angular structure of the incident beam, and its focal quality is best preserved.

-> We will keep pumps below this limit in the beam combiner to maximize focal quality.

A NIF target is designed to maximize energy transfer to a single beam with the properties needed for a pump

- To maximize single beam energy we:
  - have designed a target to initially produce plasma conditions similar to the beam crossing region of the ignition target but with longer interaction length (to reduce the effect of saturation) and minimal absorption or defocusing of the beam.
  - Have maximized energy transferred to a single high quality beam by separately shifting its frequency from that of the other crossing pump beams.
  - Will verify the energy and focal quality of the amplified beam by bringing it to focus on a witness foil during and initial test.



- A target that efficiently combines six NIF quads into a single 3-4 x amplified beam will enable designs of a 2[nd] stage Raman amplifier.
- Benchmarking models of power transfer and its saturation will provide confidence in future designs with still larger energies and larger numbers of combined beams.

The current 3-color tuning set-up at NIF can bring 5 pumps to resonance to amplify one beam in a uniform plasma

5 Pumps quads in a small angle Cone will have their frequency shifted to ion wave resonance:

$\omega_{pump} - \omega_{primary}$

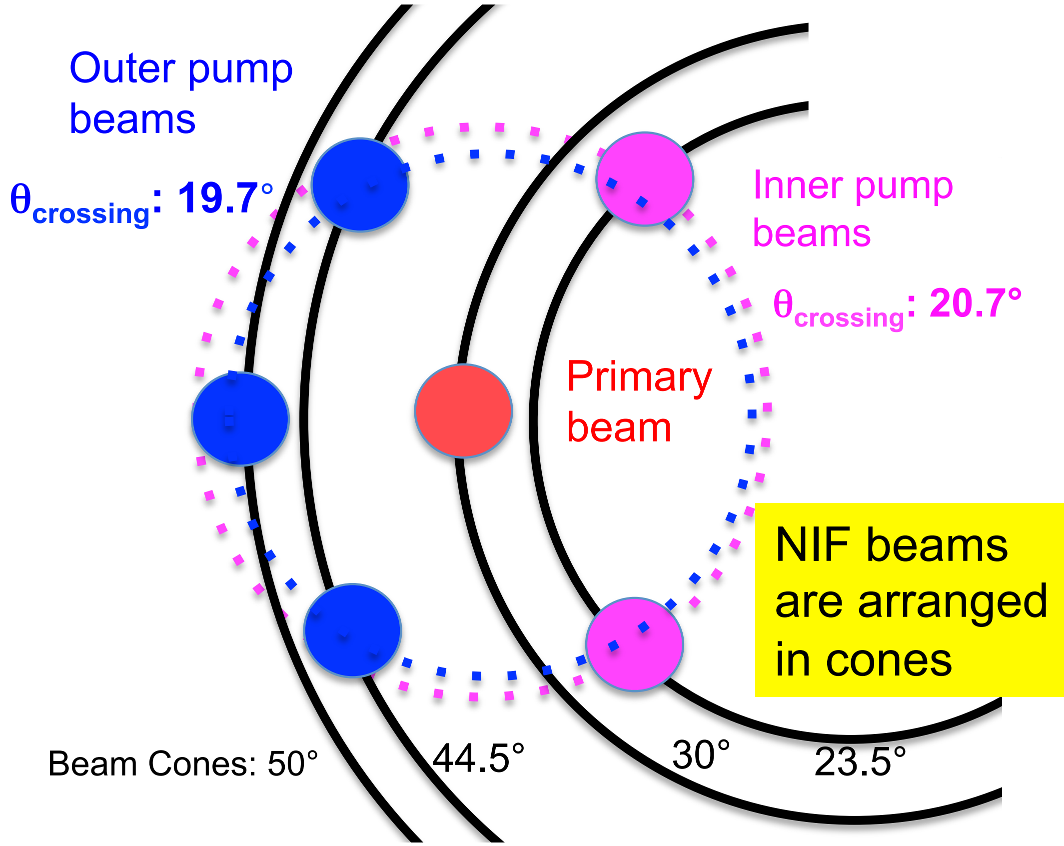
$\Delta\omega = C_s\,|k_{pump} - k_{primary}|$

$\quad = C_s\,(2\,k_o\,\sin(\theta_c/2)$

For a < 2.5 keV, $n/n_{critical}$ = 2.5% critical plasma, the wavelength Shifts relative to the primary Beam for the 6 pumps are:

$\Delta\omega_{outer}$ < 0.21 nm (0.63 nm @ 1ω)

$\Delta\omega_{inner}$ < 0.22 nm (0.66 nm @ 1ω)



NIF has this tuning capability

10 additional quads at large angle will pre-heat the gas filled target

With a uniform plasma 6 quads can be combined into a single beam!

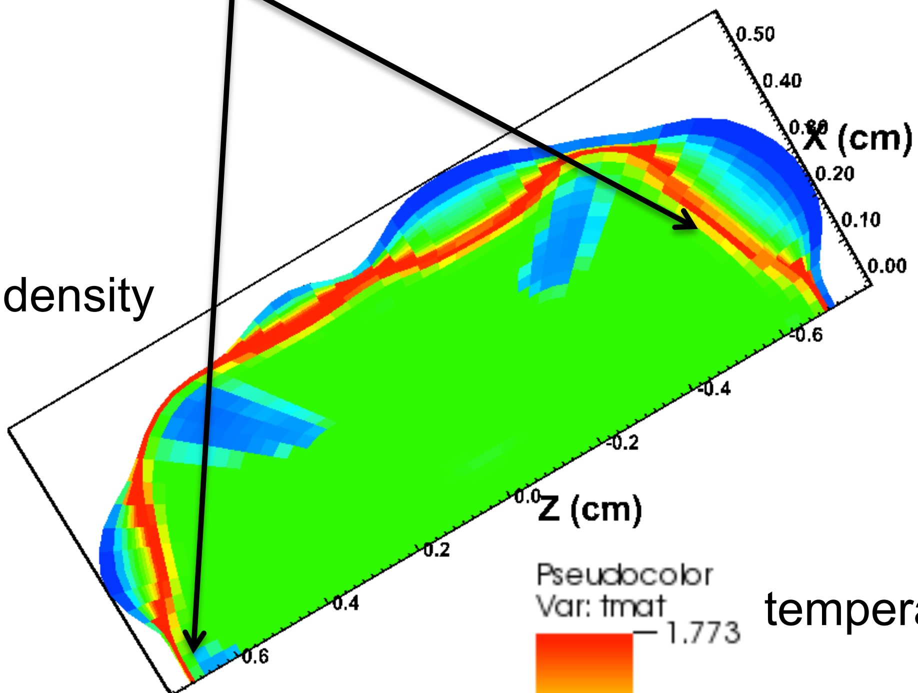
Hydra simulations with optimized pointing show the needed plasma conditions are formed by 1.0 ns

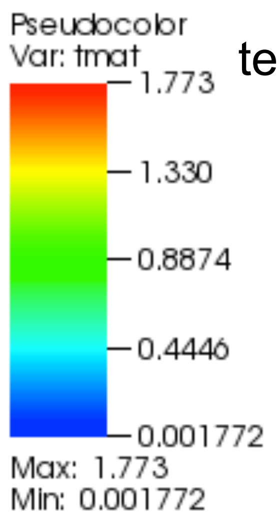
NIF

Hydra shows additional
absorption in wings of profile

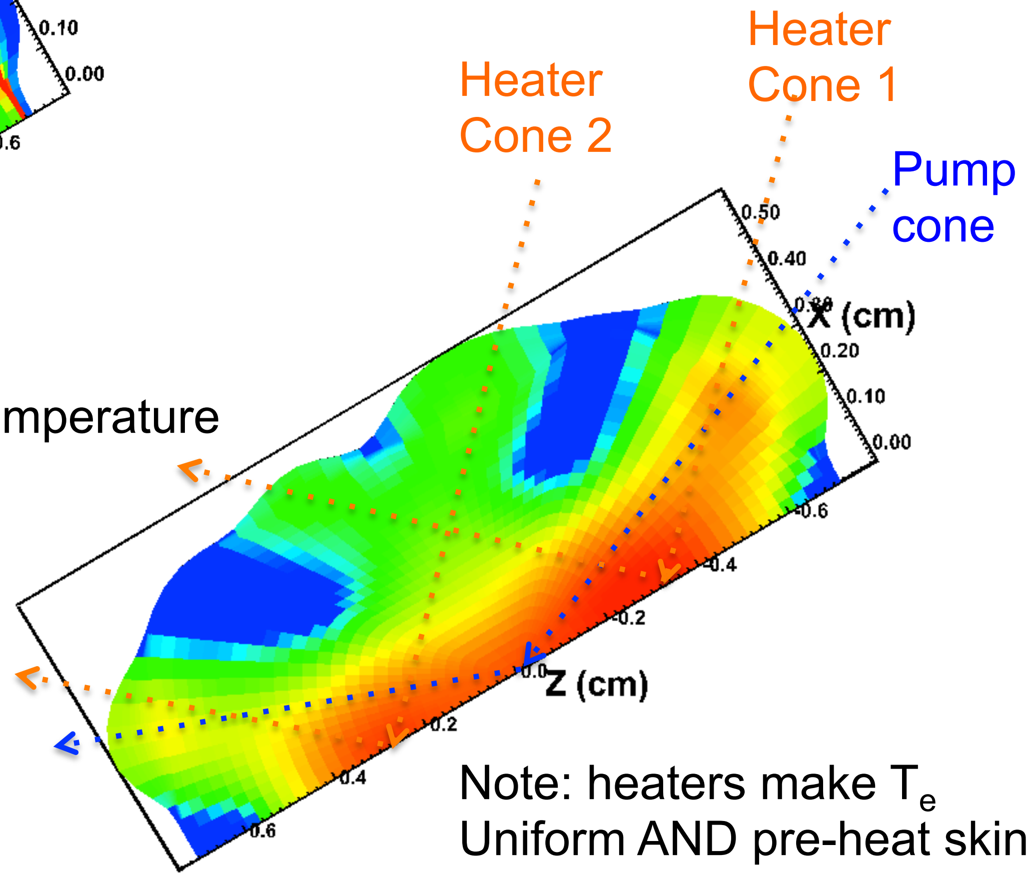
Electron density is 2.5 % crit
And uniform

density





temperature

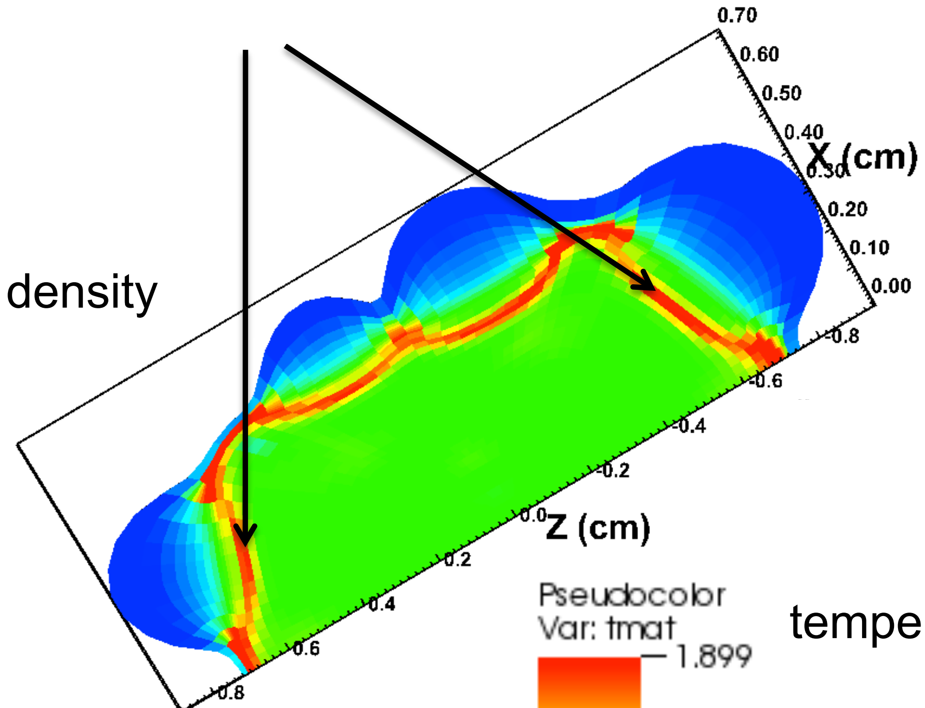


Electron temperature
is 1.6 to 1.8 keV entire
Interaction region

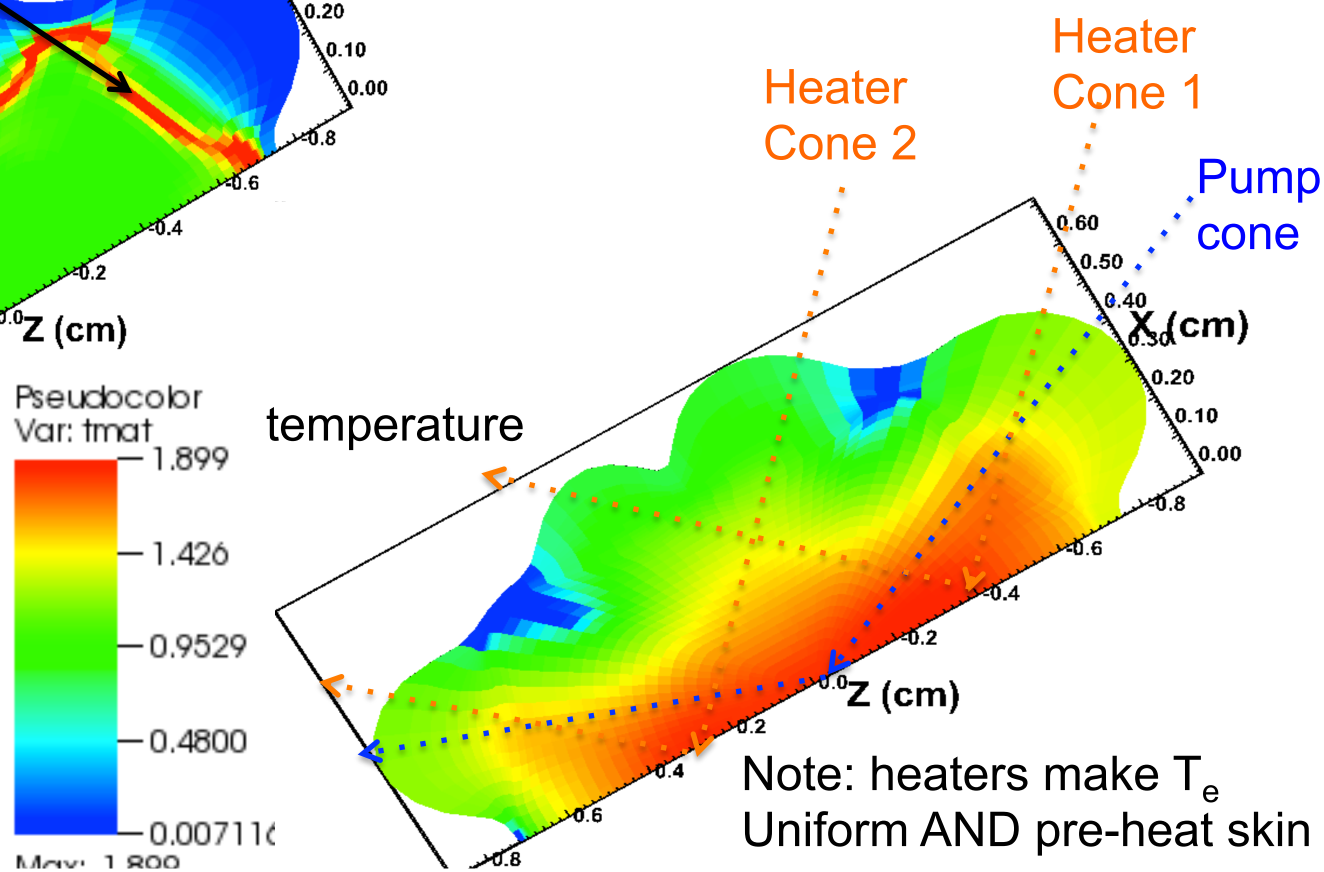
Note: heaters make T_e
Uniform AND pre-heat skin

Hydra simulations with optimized pointing show the conditions are maintained to 2.0 ns

Hydra shows additional absorption in wings of profile



Electron density is 2.5 % crit
And uniform



Electron temperature is 1.7 to 1.9 keV in entire Interaction region

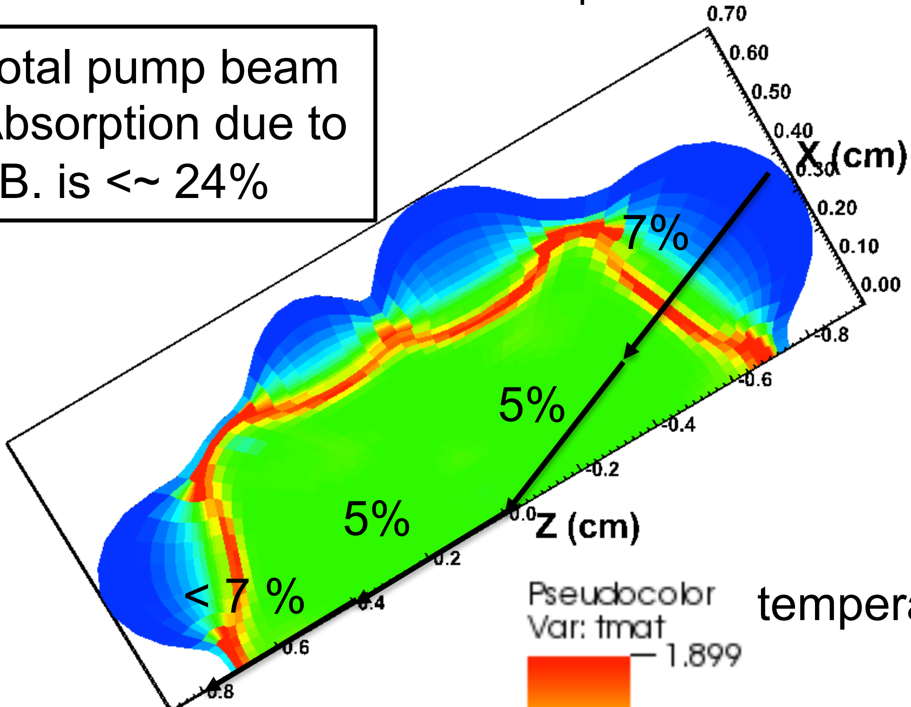
Note: heaters make T_e Uniform AND pre-heat skin

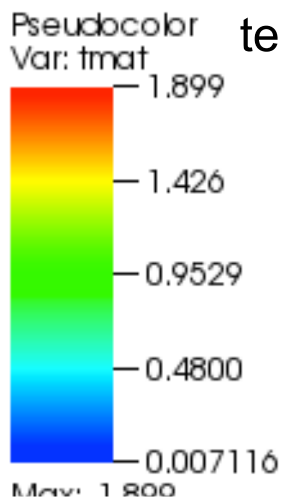
Pump beam absorption is less than 24% at 2.0 ns

Hydra shows additional
~<14% absorption in wings of profile
-> 40 kJ transmission possible

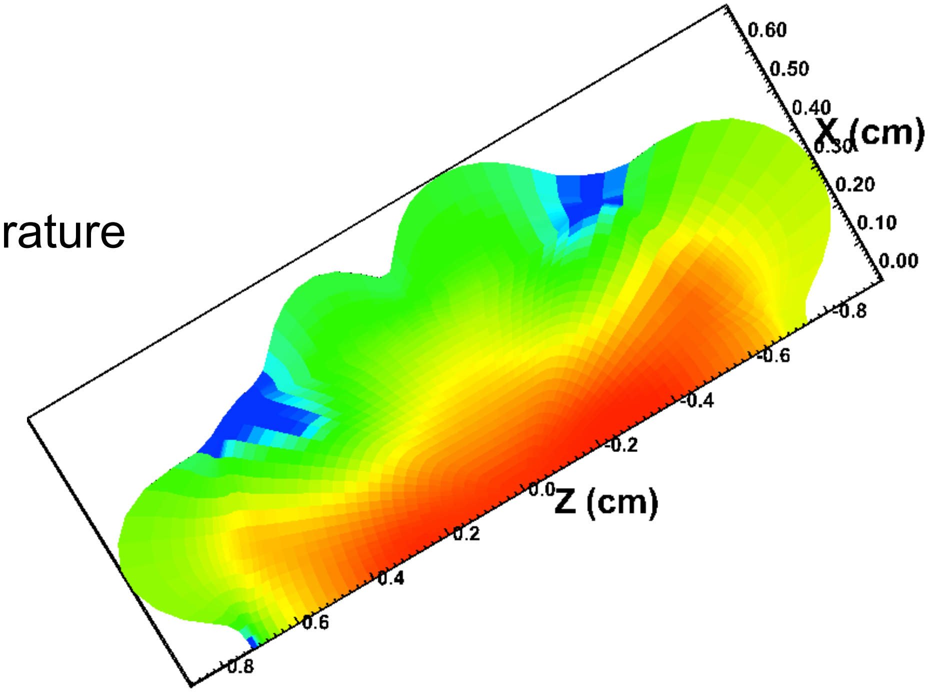
Electron density is 2.5 % crit
And uniform

Total pump beam
Absorption due to
I.B. is <~ 24%





temperature

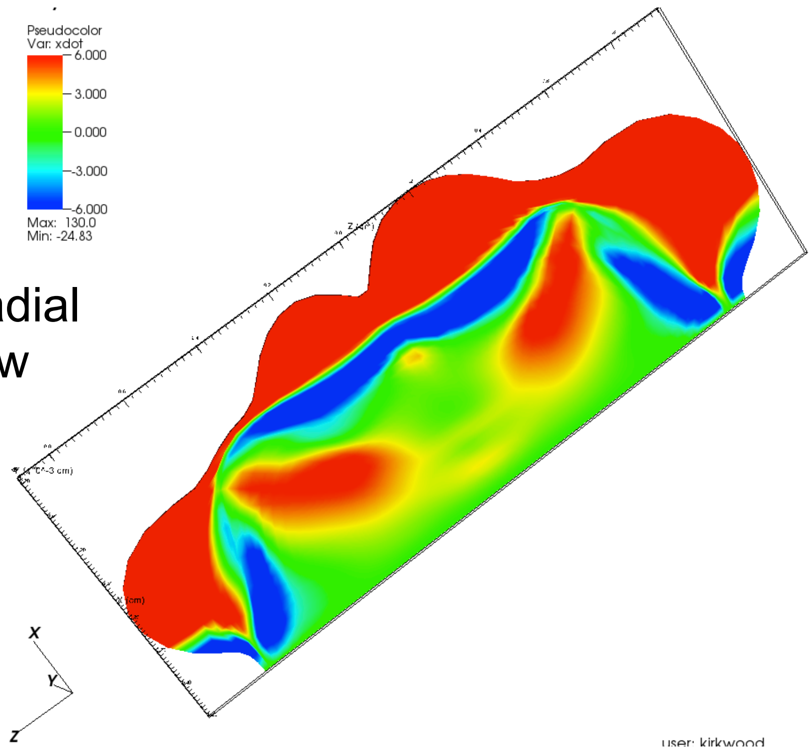


Electron temperature
is 1.7 to 1.9 keV in entire
Interaction region

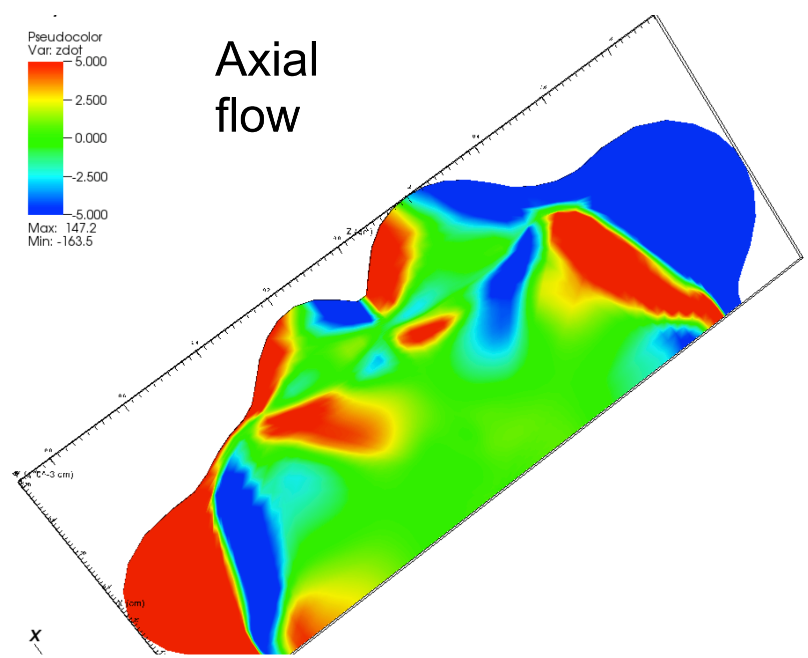
Flows are also minimal up to 2.0 ns allowing pumps to be resonant over the whole volume

Electron density is 2.5 % crit
And uniform

Radial
flow



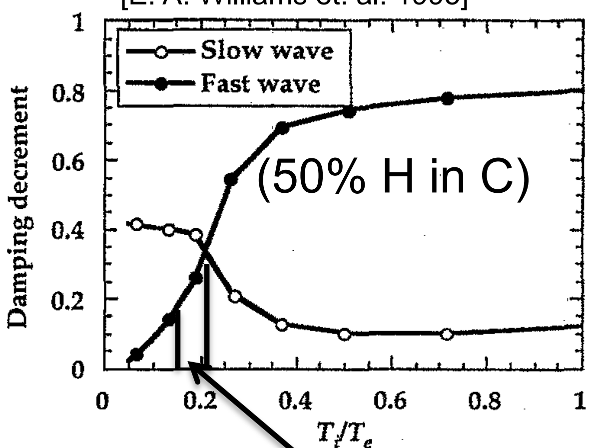
Axial
flow



Ion wave aligned flow
Velocities are < 3
cm/microsecond
(< 0.08 M) throughout
Interaction volume

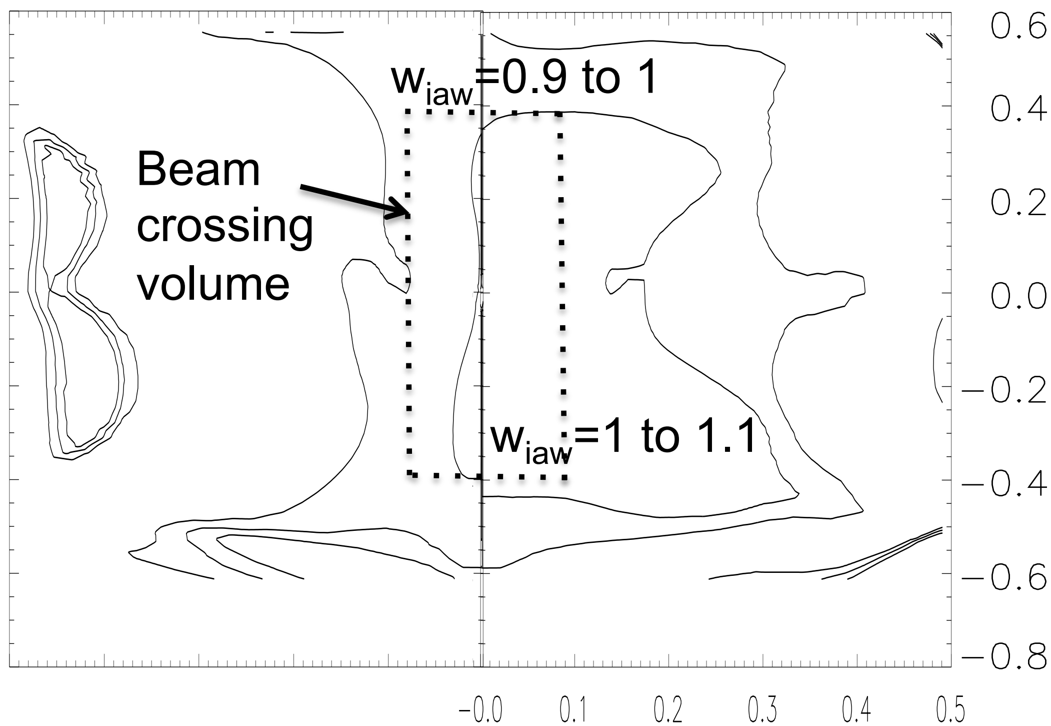
Adding a fraction of H to He will produce ion wave damping rates of 0.1 to 0.2 in a cryo target

[E. A. Williams et. al. 1995]



Combiner target conditions:
$Im(w_{iaw})/Re(w_{iaw})$ ~ 0.15 to 0.3

Hydra contours for I.A.W. frequency
= [0.9, 1, 1.1] x $(w_1\text{-}w_2)$



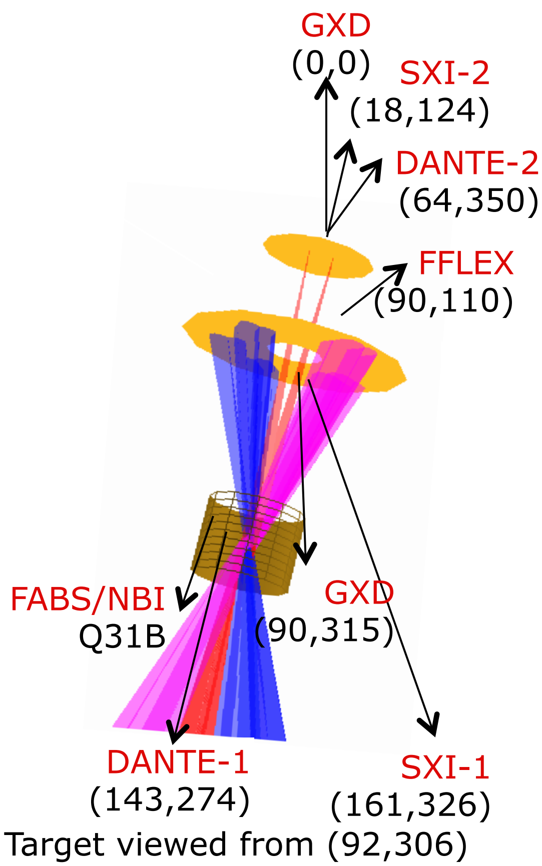
Ignition studies indicate with 33% partial pressure of H_2 in He gas the ion wave damping rate should be >10% of the ion wave frequency, so that the entire beam crossing volume can be within the resonance width.

Target can also be tested at room temperature with C_5H_{12} gas (with greater absorption).

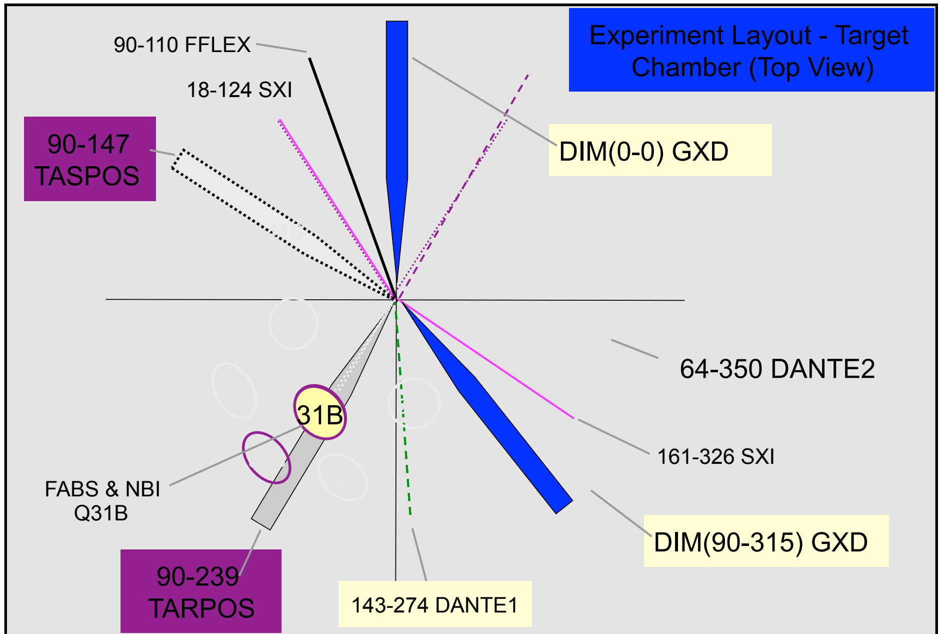
Project Name: *Beam Combination Demonstration*

Diagnostic Configuration

Diagnostics required:



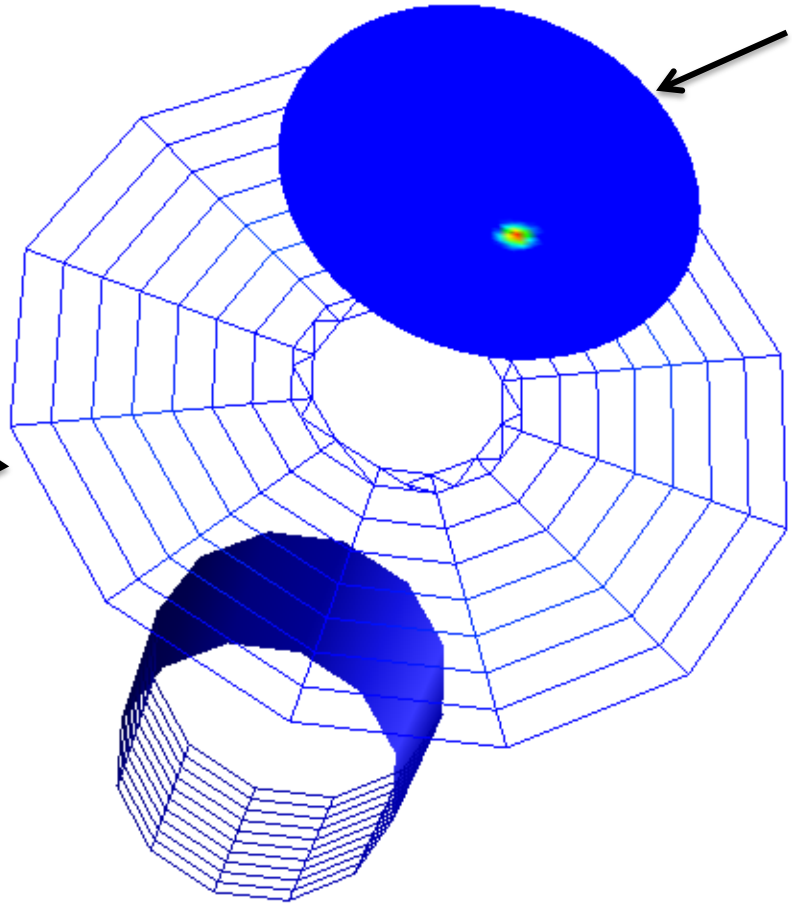
Experimental set-up: One for each unique illumination AND diag config, e.g. if you change either, requires a different setup
Priority: (1: must have,2:like to have , 3: ride-along) Type: (1:New diag, 2:major mod, 3: minor mod or existing)



Diagnostic	Location	Pri.	Type	Calib
GXD	DIM 90-315	1	3	Pre-shot
DANTE-1	143, 274	1	3	Pre-shot
GXD	DIM 0,0	1	3	Pre-shot
FFLEX	90, 110	2	3	Pre-shot
FABS/NBI	Q31B	1	3	Pre-shot
SXI [L,U] (1,2)	161,326 18, 124	2	3	Pre-shot
DANTE-2	64, 350	2	3	Pre-shot

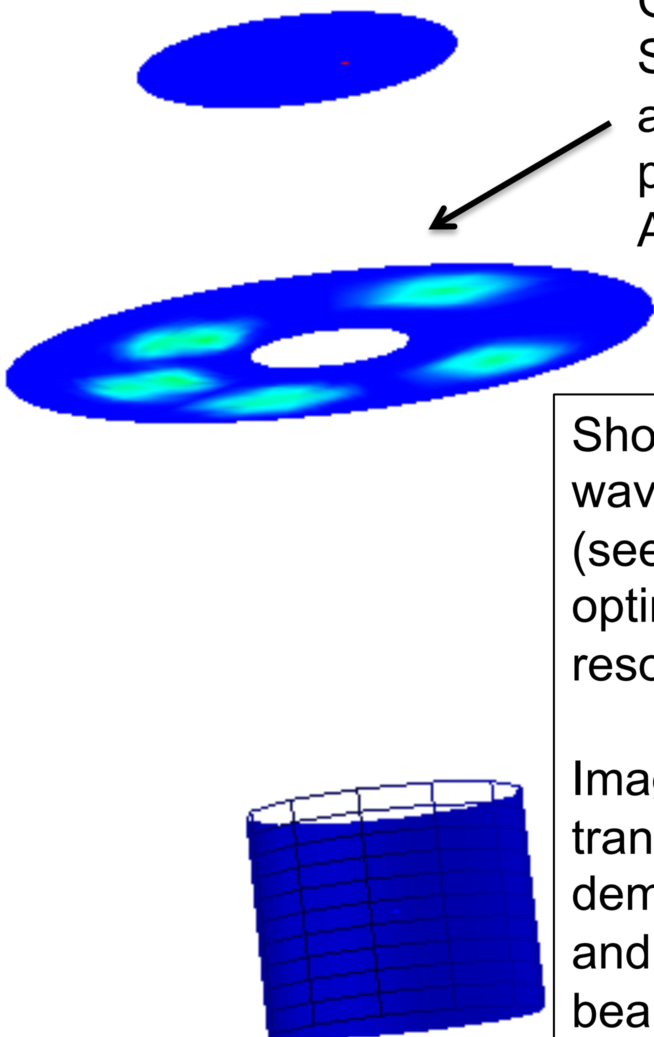
A GXD at the top of the chamber will image focal spot brightness and quality vs. time

Thin disk allows GXD imaging of amplified beam spot from back side.



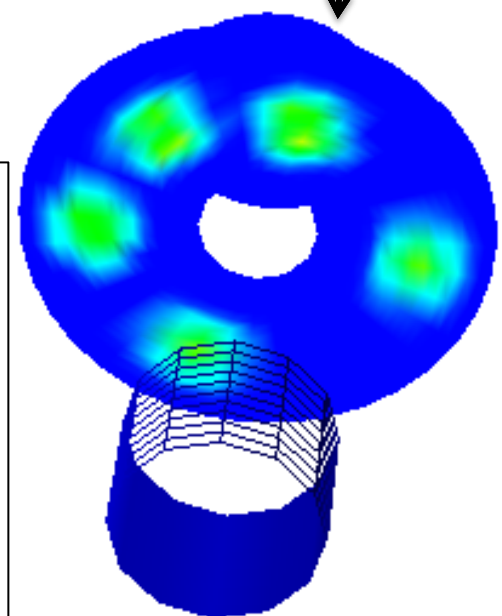
Thick disk blocks pump beams for Dante and GXD

The NIF SXI and a GXD in a standard location (90/315) will image pump beam brightness and time history



GXD sees all pump Spots (albeit at a steep angle) and will measure pump depletion vs. time AND beam.

SXI gets clear view of 4 pump spots from bottom



Shots with a different wavelength on the 30° (seed) beam will optimize power transfer resonance.

Imaging pump beam transmission will demonstrate depletion and allow beam to beam variation to be studied

Conclusions

- A 5 quad SBS combiner has been designed to produce ~ 40 kJ of energy in a single NIF beam and can provide a high energy, collimated ns duration beam attractive for driving a ~< ps pulse Raman amplifier in a second stage.

- The physics and conditions of the beam combiner are very similar to the ignition target which produces up to 2x beam amplification regularly and reproducibly.

- Successful demonstration of a single beam combiner at NIF will increase the confidence in the design of multi – 100 kJ plasma amplifiers/compressors for large laser facilities.

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NIF